Inversion for Geoacoustic Model Parameters
in Range-Dependent Shallow Water Environments

N. Ross Chapman
School of Earth and Ocean Sciences
University of Victoria
PO Box 3055
Victoria, B.C. V8W 3P6
phone: (250) 472-4340   fax: (250) 472-4620   email: chapman@uvic.ca

LONG TERM GOALS

The ability to predict sound propagation in shallow water is limited by the knowledge of the geoacoustic properties of the bottom. The long term goals of this research are: (1) to investigate full field inversion methods for estimating parameters of geoacoustic models of the ocean bottom and the associated uncertainties in the model parameter values; and (2) to evaluate the performance of the geoacoustic inversion techniques for applications over a broad frequency band in range dependent shallow water environments. This work is set within the wider context of research to understand the physics of the interaction of sound with the ocean bottom.

OBJECTIVES

The recent ONR-sponsored research program in benchmarking geoacoustic inversion methods has demonstrated the maturity of the inversion methods against synthetic data for range-dependent shallow water environments (Chapman et al, 2003). A critical unresolved issue is evaluation of the performance of the inversion methods for estimating geoacoustic profiles from real data at a well ground-truthed site. The experiments carried out in the SW06 Experiment during August-September 2006 on the New Jersey continental shelf have provided high quality data that can be used for evaluating and comparing the performance of several different techniques, including matched field inversion; reflection coefficient inversion and wavenumber extraction inversions.

Although the matched field inversion methods have proven to be very effective in many experimental scenarios, there is a remaining question of how well the methods perform in the presence of unknown variations of the environmental parameters. Effects due to spatial variations in the ocean bottom parameters such as water depth and sediment sound speed have been investigated in various numerical simulation studies. However, uncertainties in the water sound speed will also affect the inversion performance, because the matched field methods are based on acoustic propagation models that require information about the sound speed profile in the water to predict the replica fields. Uncertainties in the water sound speed can arise due to internal waves, eddies, fronts and tidal currents that generate local inhomogeneities in the water at different spatial and temporal scales.

The overall objectives in this proposal are based on use of the low and mid frequency data obtained in the SW06 experiment: (1) Evaluate the performance of low frequency (< 1 kHz) matched field geoacoustic inversion for estimating geoacoustic models in a range dependent continental shelf break environment; (2) Determine the impact of uncertainties in the water column sound speed profile (due

Report Documentation Page

1. REPORT DATE	2. REPORT TYPE	3. DATES COVERED
30 SEP 2007	**Annual**	**00-00-2007 to 00-00-2007**

4. TITLE AND SUBTITLE	5a. CONTRACT NUMBER
Inversion For Geoacoustic Model Parameters In Range-Dependent Shallow Water Environments	5b. GRANT NUMBER
	5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)	5d. PROJECT NUMBER
	5e. TASK NUMBER
	5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)	8. PERFORMING ORGANIZATION REPORT NUMBER
University of Victoria,PO Box 3055,Victoria, B.C. V8W 3P6, ,	

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSOR/MONITOR'S ACRONYM(S)
	11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT

Approved for public release; distribution unlimited

13. SUPPLEMENTARY NOTES

code 1 only

14. ABSTRACT

The ability to predict sound propagation in shallow water is limited by the knowledge of the geoacoustic properties of the bottom. The long term goals of this research are: (1) to investigate full field inversion methods for estimating parameters of geoacoustic models of the ocean bottom and the associated uncertainties in the model parameter values; and (2) to evaluate the performance of the geoacoustic inversion techniques for applications over a broad frequency band in range dependent shallow water environments. This work is set within the wider context of research to understand the physics of the interaction of sound with the ocean bottom.

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**Same as Report (SAR)**	**6**	

to volume inhomogeneities in the water column) on geoacoustic inversion, and develop effective ways to account for the uncertainties in the inversion; (3) Investigate methods for geoacoustic inversion in the mid frequency band (1 – 5 kHz); (4) Determine the geoacoustic model parameters that are most critical for predicting sound propagation over the LF and MF bands. The research described here addresses the first two objectives that are listed above.

APPROACH

The research is focused on the low frequency data obtained in a collaboration during the SW06 experiment with Dr. W. S. Hodgkiss. These data provide the means to evaluate the performance of inversion methods in short and long range experimental geometries, and interpret the estimated model parameters in terms of physical properties of the bottom materials, particularly, the frequency dependence of sound speed and attenuation in the sediment. The research is based on Bayesian matched field inversion.

Description of the Experiments: The data used in this paper were recorded on a bottom-moored vertical line array deployed by Dr. Hodgkiss and his research group. The shelf break location (Fig. 1) was specifically chosen to amplify the impact of uncertainties in the water sound speed profile on geoacoustic inversion performance due to the shelf break front, a salinity/density front and current that meanders near the shelf edge, and the frequent presence of warm-core eddies shed from the Gulf Stream. The location was also the site of high frequency acoustic measurements (2–20 kHz) that were done prior to the low frequency experiments (D.J. Tang and P. Dahl, personal communications).

The vertical array consisted of 16 hydrophones equally spaced at 3.75 m, with the bottom-most sensor 8.2 m above the sea floor [1]. The sampling rate at each sensor was 2000 samples/s, and the data were stored on a hard drive in an underwater pressure case at the base of the array. Array depth was monitored by a pressure sensor that was located 0.5 m above the top-most hydrophone. Tilt and compass direction were also monitored at the same location on the array. A J–15 sound projector was used to generate low frequency signals in one of three modes: a set of CW tones, either four tones from 53 to 253 Hz, or five tones from 303 to 953 Hz; or an LFM sweep from 100–900 Hz.   The projector was towed from the R.V. KNORR on a track that passed through the deployed array locations, and the track was repeated for each type of sound source waveform. This report focuses on the analysis of data from a single radial track from the vertical array out to ~8 km along one of the chirp survey lines. The source ship stopped at stations of 1, 3, 5 and 7 km and transmitted the CW tone sequences for about five minutes, using a source depth of 30 m. The water depth was range independent out to about 3 km, and gradually increased to about 83 m over the remainder of the track.

Sound speed profiles in the water were measured at each station using a CTD. The variation in the profile was significant over relatively short time scales and distances, due to the proximity of the shelf break. The variation in the profiles is shown in Fig. 2 for the measurements made during the experiment.   A high resolution sub-bottom survey was carried out prior to the experiment using a chirp sonar (2–12 kHz) to define the sub-bottom profile along the radial track from the array. The chirp data revealed well-resolved structure down to about 30 m, most prominently showing the 'R' reflector at about 20 m. This interface, which is pervasive in the region, was overlain with alternating layers of sand and mud. In situ sediment probes were also deployed at selected sites (D.J. Tang and A. Turgut, personal communications). The preliminary analysis of these data indicated a sound speed value of around 1620 m/s for the sea floor sediments near the vertical array. However, the sea floor sediment type varied significantly over the region, most notably at 10-20 km sand ridges roughly parallel to the shelf break.
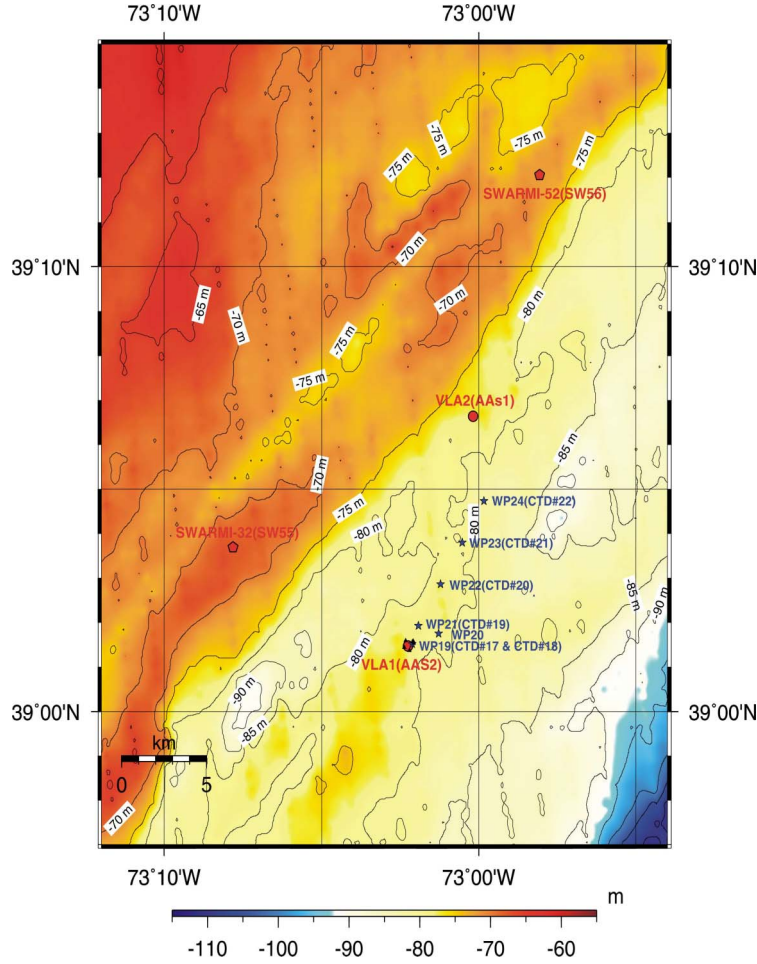
Figure 1. Location of the experiments (VLA1) on the New Jersey Shelf.

Geoacoustic inversion method: The inversion method is based on Bayes rule that relates conditional probabilities of the measured data and possible models. The Bayesian solution combines prior knowledge about the model parameters with the information about the parameters that is contained in the data.   The method is applied here to the multi-tonal CW data to estimate geoacoustic profiles for range dependent environments, using a segmentation concept in which prior information from inversions for the initial range segments is used to invert subsequent segments. The uncertainty in the water column sound speed is accommodated by inverting for the parameters of an 'average' sound speed profile that is defined by a set of empirical orthogonal functions (EOFs).   The method accounts for mismatch between the measured data and calculated replica fields due to uncertainties in the ocean environment by estimating a data error covariance matrix. The covariance matrix is estimated from an ensemble of data windows that contain the data error information, following a method developed previously in our research program (Jiang, Chapman and Badiey, 2007).

Geoacoustic model parameterization: The geoacoustic model consisted of a sediment layer over a half space. The sediment was modelled as an inhomogeneous sound speed layer, with constant density and attenuation. However, the attenuation and density of the half space were held at constant values. In

3

addition, geometric parameters of the experimental configuration were also estimated. These included the range, source depth, array depth (of the bottom-most hydrophone), array tilt and compass direction and the water depth. Although the values of these parameters were known from independent measurements, the geometric parameters were included in the inversions as a consistency check for the geoacoustic inversion. Accurate estimates of the geometric parameters were used as a qualitative measure of the inversion performance.
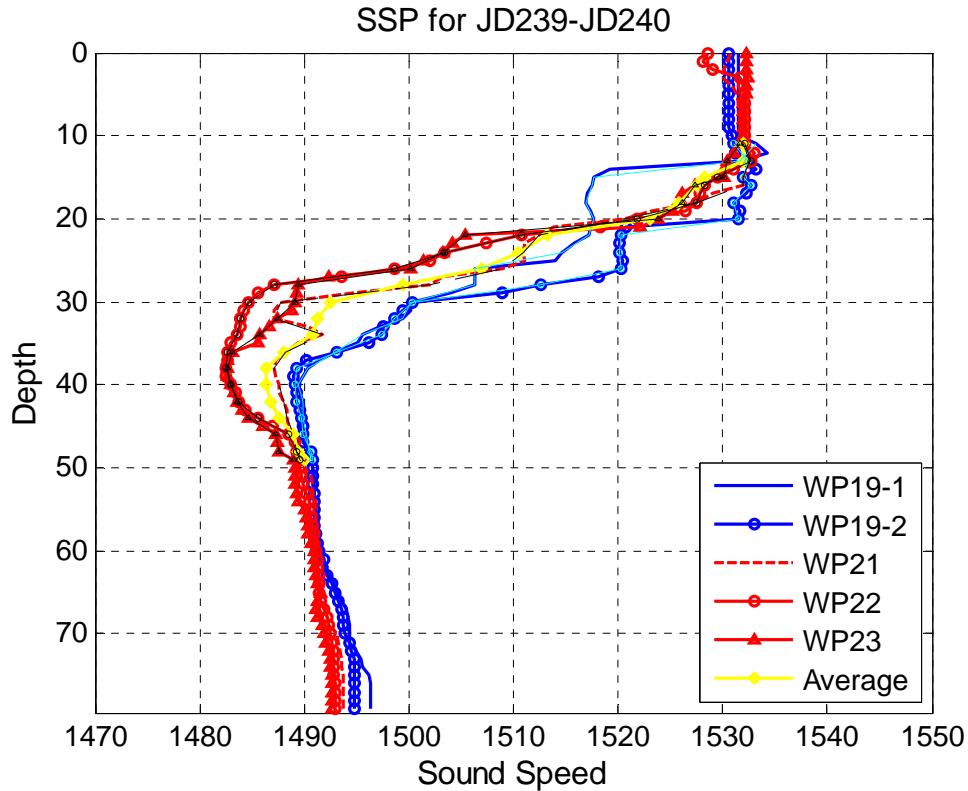

Figure 2. Sound speed measurements at the receiver (WP 19)
and at the source (WPs 21-23) during the experiment.

WORK COMPLETED

Acoustic data were copied during the experiment to provide a complete set of the recorded data. From these data, the data for the radial track line were selected and processed to obtain time series of the spectral components of the transmitted tones in the two low frequency bands. Matched field inversions were carried out for the data from the experiments at 1, 3 and 5 km ranges.

RESULTS

The estimated values for the geoacoustic parameters are displayed in the seven panels in Figure 3. At a range of 1 km (row a), the inversion is sensitive to the sound speed in the upper layer of sediment. The inversion indicates a thickness of about 22 m for the layer, consistent with the expected depth of the 'R' reflector from the chirp sonar survey. Within the layer, the sound speed decreases from a value of 1644 m/s at the sea floor to around 1560 m/s at the base of the layer. The sound speed increases to

4

about 1855 m/s across the interface at the base of the sediment layer. In comparison with ground truth data, the preliminary analysis of measurements of sediment sound speed at the sea floor from the in situ probes near the vertical array indicate sound speeds of ~1620 m/s. The variation with depth within the layer is consistent with results from deeper cores in the vicinity that show decreasing sound speed at depths between 3-15 m due to embedded layers of clay and silt. The sound speed increase at the 'R' reflector is between 1750-1850 m/s.

The other geoacoustic parameters are not well estimated in this experiment, as judged by the large spread of values in the distributions in the lower panels of Figure 3. Sensitivity to attenuation increases for the longest range (row c); this is physically reasonable since the matched field inversion is sensitive to attenuation by means of the loss in energy in the propagated field. Attenuation is assumed to be a general loss parameter that could include effects of scattering and intrinsic absorption of sound in the sediment. It is modelled as $\alpha \phi^B$, where α is the attenuation in dB/m at 1kHz.

The inversion accounted for unknown spatial variation in the water sound speed by inverting for the coefficients of an empirically derived profile that provided the best match between the experimental data and the modelled field at the array. Viewed from another perspective, the empiricial sound speed profile allows the inversion to obtain the best focus of sound energy at the array, given the presence of sound speed variations in the water. Only the first four coefficient of the EOFs were included in the inversion since they account for over 99 percent of the fit for the profile shape, and the first EOF itself accounts for over 70 percent of the fit.

The inversion estimates for the geometric parameters were all very close to expected values from independent measurements during the experiment. Although this is only a qualitative indication of the inversion performance, the close agreement with the known values for the geometric parameters provides confidence overall in the estimated values of the other parameters, and support for the approach used to account for the water sound speed variations.

IMPACT/APPLICATIONS/TRANSITIONS

The project demonstrated that the uncertainties in the water column had significant impact on the performance of matched field geoacoustic inversion. The results of the inversion showed that uncertainty in the water column can be accounted for using an averaged sound speed profile defined by empirical orthogonal functions that are estimated in the inversion.

The experimental data from the SW06 geoacoustic experiments is high quality data that can serve as benchmark data for evaluating the performance of geoacoustic inversion methods. The research related to the analysis and interpretation of data from the geoacoustic experiments in SW06 is connected with the research projects of the following: W. S. Hodgkiss (MPL, SCRIPPS); D. Knobles (ARL:UT); G.V. Frisk (Florida Atlantic); K. Becker (ARL Penn State); P. Dahl and D.J. Tang (APL UW).
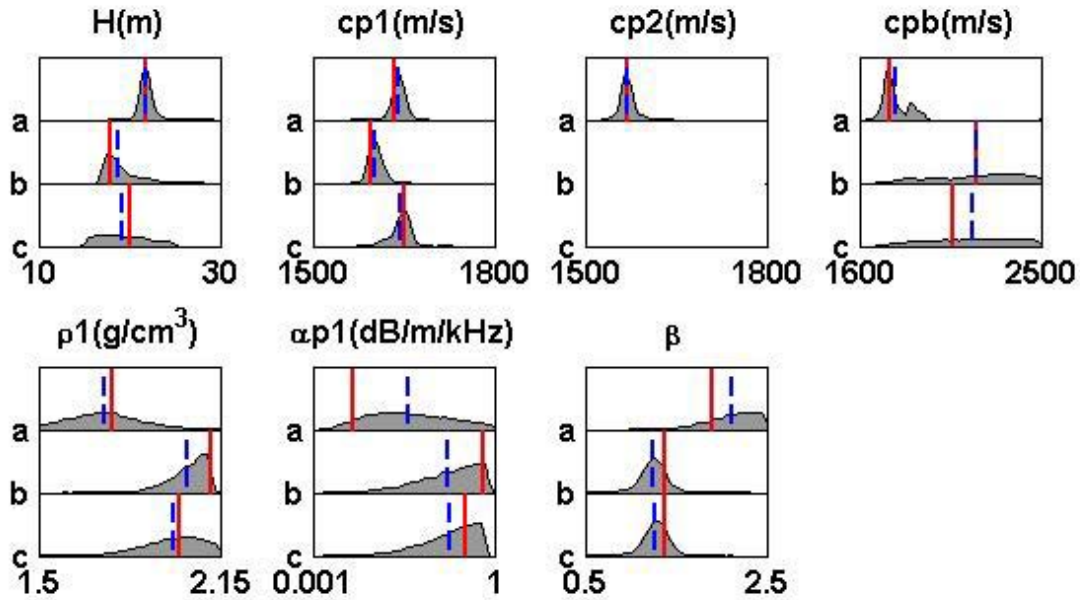
Figure 3. One dimensional marginal distributions for the geoacoustic model parameters: H (water depth); cp1 (sediment sound speed at top of sediment layer): cp2 (sediment sound speed at bottom of sediment layer): ρ1 (sediment density); αp1 and β (sediment attenuation); and cpb (half space sound speed).

REFERENCES

Chapman, N.R., ChinBing, S., King, D. and Evans, R.B., Benchmarking geoacoustic inversion methods for range dependent waveguides, IEEE J. Oceanic Eng., **28**, 320-330 (2003).
Yong-Min Jiang, N. Ross. Chapman and Mohsen Badiey, "Quantifying the uncertainty of geoacoustic model parameters for the New Jersey shelf by inverting air gun data," J. Acoust. Soc. Am. **121,** 1879-1895 (2007)

PUBLICATIONS

Yong-Min Jiang, N. Ross. Chapman and Mohsen Badiey, "Quantifying the uncertainty of geoacoustic model parameters for the New Jersey shelf by inverting air gun data," J. Acoust. Soc. Am. 121, 1879-1895 (2007).
Y. Jiang, N. R. Chapman, H. A. DeFerrari, Geoacoustic inversion of broadband data by matched beam processing, J. Acoust. Soc. Am. 119, pp. 3707–3716, 2006.

HONORS

N.R. Chapman was elected Chair of the Technical Committee on Acoustical Oceanography of the Acoustical Society of America, 2004-2007.
The paper 'Benchmarking geoacoustic inversion methods for range-dependent waveguides' in IEEE Journal Oceanic Eng. was determined by Thomson ISI as one of the most cited recent papers in the field of Engineering, May 2004